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Dynamic Range Improvement of GMRT Low Frequency Images

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Abstract.
This paper outlines some new observational and data processing techniques for enhancing the dynamic range of low frequency images obtained with the Giant Metrewave Radio Telescope. We illustrate new software tools developed to facilitate visibility editing and calibration as well as other preprocessing required to enhance the dynamic range of images from a planned survey.

1. Introduction

The measured system parameters of the individual elements of the Giant Metrewave Radio Telescope (GMRT) (Swarup et al. 1991) indicate that the rms sensitivity achieved for GMRT images for a full synthesis at the lowest frequencies are only comparable to those theoretically expected for a 10-minute snapshot observation (GMRT specs). In this paper, we address some of the possible ways of improving the situation and give some preliminary results from useful software tools being developed for visibility editing and preprocessing.

Firstly, we note that the traditional integration times of several seconds for each visibility point are a potential source of systematic biases in the measured visibilities in the presence of bursty interference and fast phase variations expected from ionospheric effects at low frequencies. For this, we suggest taking advantage of the short term integration of 0.13 second permitted by the GMRT correlator hardware. Secondly, by planning observations in terms of independent observing sessions (different days) with identical antenna pointing and sidereal time range, identification and editing of corrupted data becomes possible by examining the cross-correlation of visibilities corresponding to identical sidereal times for each baseline. In other words, we advocate splitting the overall integration time on a field into identical observing sessions spread over multiple days. Finally, we note that forthcoming geosynchronous navigation satellites (Kibe 2003) provide an interesting co-location of facility for a continuous measurement of ionospheric delay variations along the line of sight of the satellite from the array. The best exploitation of this can be made with transit observations with the GMRT, as indicated by the novel dual-frequency mode described in Section 2.

In order to support transit observations and fast sampling of visibilities, some minor modifications were carried out on the data acquisition programs at the GMRT. More importantly, the large volume of data generated, as well as the need for nonstandard data preprocessing prompted us to develop new tools for facilitating visualization, automatic editing and calibration suitable for the

observing techniques suggested by us. Some examples from the use of these tools are presented in Section 3.

2. Trial Observations

In order to carry out field trials of our observing methodology, we used the GMRT in transit mode over an identical LST range on three days. The specific choice of antenna pointing was made to ensure that a geosynchronous satellite (Inmarsat 4F1) broadcasting L-band navigation signals was always within the field of view. The navigation signals were test signals centered at 1176 MHz being broadcast by the Indian Space Research Organization (ISRO) as part of a Wide Area Augmentation Service (WAAS) (Kibe 2003) trial run. Since the satellite signals were strong enough to be picked up directly by the L band feed of GMRT without requiring the dish collecting area, three of the GMRT antennas were operated in a special dual frequency mode to simultaneously receive 235 MHz and 1.17 GHz in the two IF bands. This was possible since the L band feed of the GMRT looks at the sky when the 235 MHz feed is facing the dish; thus enabling the 1176 MHz signal to be picked directly from the feed pointing at the sky while the low frequency signal was received by the feed facing the dish. For our observations, the GMRT antennas were nominally pointed towards the direction of the satellite in the middle of every one-hour observing session.

The use of the GMRT correlator simultaneously for the satellite and the celestial sky led to a conflicting requirement for fringe stopping. While fringe stopping was necessary for the celestial signal to prevent loss of correlation due to fringe winding, the absence of fringing for a geosynchronous satellite would result in decorrelation of the satellite signal due to substantial phase winding if fringe rotation was activated. This conundrum was managed by a partial fringe stopping achieved by fooling the correlator software such that fringe winding was contained within a radian in the worst case for both the satellite and the celestial signal within the 0.13 second integration time.

The arrival time differences of a geosynchronous satellite at a small inclination (2.4^o) are expected to vary very slowly (dominantly diurnal sinusoidally), while the measured phase differences(Fig. 1) indicated small short term variations superposed on a slow drift. Such deviations from a smooth curve are due to the variation of differential delay caused by the ionosphere. These can be used to provide a direct estimate of the variation of arrival time difference caused by the ionosphere. This in turn can be used to provide a reasonable estimate of the phase variations at 235 MHz. The smooth curve by itself is useful for improving orbit estimates of the satellite, details of which will be published elsewhere.

From the point of view of low frequency imaging from the GMRT, it is significant that the scope of the Indian Satellite Navigation program has now been been widened by ISRO which plans to deploy upto 7 satellites with navigation payload in the near future, in addition to the first satellite due for launch during middle of 2009. This will give continuous and direct measurements of phase distortions along many lines of sight from the GMRT array. At any (low) frequency of observation, we can either dedicate a few GMRT antenna for such a signal acquisition, or, for the special case of 235 MHz observations,the dual frequency mode as described by us can be utilized.

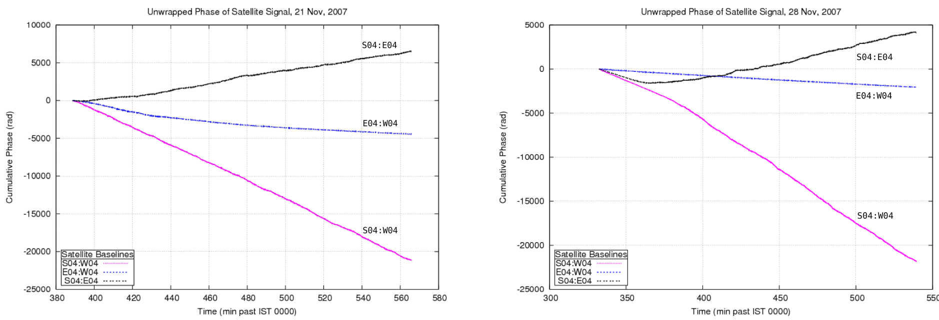

Figure 1. Satellite cumulative phase seen varying smoothly over 3hrs due to smooth diurnal sinusoidal motion of the satellite in its inclined orbit. The random jitter can be attributed to net phase distortions in the line of sight.

3. Visibility Visualization and Data Quality Analyzer

During our trial observations, the data were recorded over 16 MHz bandwidth providing a 62.5 KHz spectral resolution and an integration time of 131.072 ms, resulting in a data rate of 50 GB/Hr. Consequently, we felt the need to develop new tools for visualization and preprocessing of visibilities with particular attention to managing large volumes of data. Basic operations supported by our tool include display of visibilities and processed outputs as images, reformatting to various file formats, extraction/ reordering and recording of subsets etc., with a baseline being the operational unit. A unified callback interface exists which simplifies the plugging-in of modules for different operations like correlation between different days, FFT along any axis etc. In our implementation, any data selected by the user is extracted by a file reader object, pooled by a data formatter object and processed by a centralized processor object, which interfaces with a per baseline display object. A central controller manages the graphical user interface (GUI) and sequences all the desired operations.

Fig. 2 gives a snapshot of our tool GUI in action. A feel for the capability of managing large volumes of data by our tool can be obtained by noting that each frame in Fig. 2 corresponds to about a Megabyte of visibility data and our tool can refresh a dozen such frames simultaneously at 100 Hz. Each horizontal panel shows interday visibility cross-correlations and includes several frames of 256 x 400 pixels. In a given frame, while columns correspond to the 256 spectral channels (16 MHz), each row corresponds to a time slice (0.131s).

A major new feature of our tool for data editing pertains to correlations of visibilities from multiple sessions with identical antenna settings and LST ranges. Fig. 2 shows such a correlation, in which regions of poor correlation can be seen to be darker in color and correspond to local effects like interference which will be uncorrelated from one day to the other while the sky contribution should be identical.

An indication of the nature of RFI at GMRT is given by our analysis of 8-second blocks of visibilities, which correspond to typical GMRT integration times. In almost 70-80% of such 8-second blocks, we found that $6 - 10\sigma$ deviations occurred about 10-20% of the time, not necessarily contiguously within the block. Such deviations remain undetected by conventional flagging on visibilities

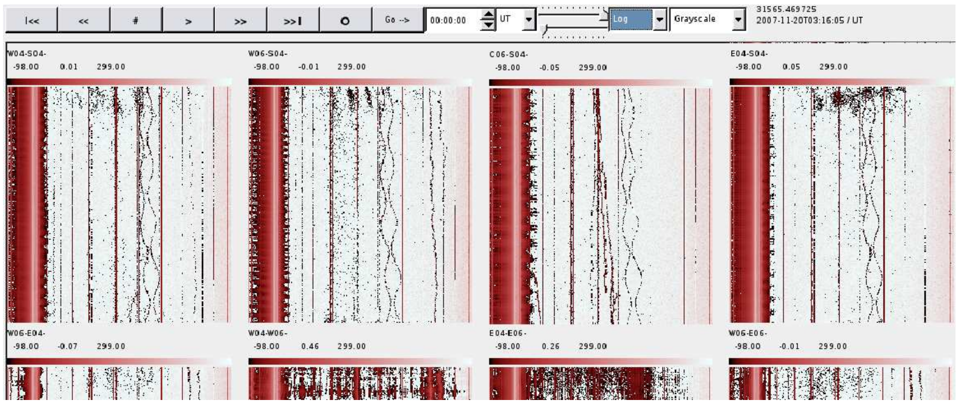

Figure 2. Per channel (X axis) visibility cross-correlations over identical LST ranges on two days. Regions of high brightness over time (Y axis) indicate consistent data. Each frame in the panel represents the indicated baseline.

integrated over 8 seconds or more. In contrast, they introduce systematic errors in the form of biases in the mean visibility which can seriously affect the quality of images.

4. Conclusion

A new tool has been developed for visualization and efficient analysis of high volume interferometric datasets, while providing users with different descriptions of errors in the dataset. These can provide better insights towards the quality of data and help form a more reliable dataset to be presented to regular post-processing and imaging software. Support for transit observations with the GMRT are discussed, which is expected to provide an efficient observational mode for a rapid, low frequency survey.

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References

Swarup, G., Ananthakrishnan, S., Kapahi, V.K., Rao, A.P., Subrahmanya, C.R., Kulkarni, V.K., 1991, Current Science, 60, 95

`http://gmrt.ncra.tifr.res.in/gmrt_hpage/Users/doc/manual/UsersManual/node13.html#244`

Kibe, S.V., 2003, Current Science, 84, 1405